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# DESIGN AND CONSTRUCTION OF A HELMHOLTZ COIL MAGNETIC TEST CELL

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A Helmholtz coil magnetic test cell was designed and constructed in order to properly test various systems of interest which involve sensing a magnetic environment as part of their normal function. The electric current feed to the coil is provided by a low impedance, close-spaced busbar assembly so that nonsolenoidal magnetic fields are kept to a minimum. Based on the calibration run described in this report, the Helmholtz coil is seen to provide a useable magnetic field for the testing of smaller items. A more precise calibration and an impulse driver circuit designed to exactly simulate the required drive current waveform would substantially increase the ability to perform tests on an absolute basis. As it stands, this Helmholtz coil and its driver circuit is quite useful for a number of testing purposes.

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# I. INTRODUCTION

Various systems of interest involve sensing a magnetic environment as part of their normal function. A magnetic field exposure cell was constructed in order to properly test these systems. The classic magnetic exposure cell is the Helmholtz coil, a two–loop solenoidal inductor of sufficiently large dimensions, with care being taken to minimize any non–solenoidal flux lines.

# II. DESIGN

Since most of the systems to be tested were about one foot in maximum dimension, it was decided to build a half–meter Helmholtz coil. Such a coil has its loops 0.5 meter in diameter with the loops spaced 0.5 meter apart. Such a design is shown in Figures 1 and 2, which are the front and side views, respectively, of the Helmholtz coil assembly. The electric current feed to the coils is provided by a low impedance, close–spaced busbar assembly so that non–solenoidal magnetic fields could be kept to a minimum. Although the required operation needs only a few tens of volts, the busbar insulation was made sufficiently robust to withstand a few thousand volts if the generation of intense short pulse fields becomes necessary for some future application.

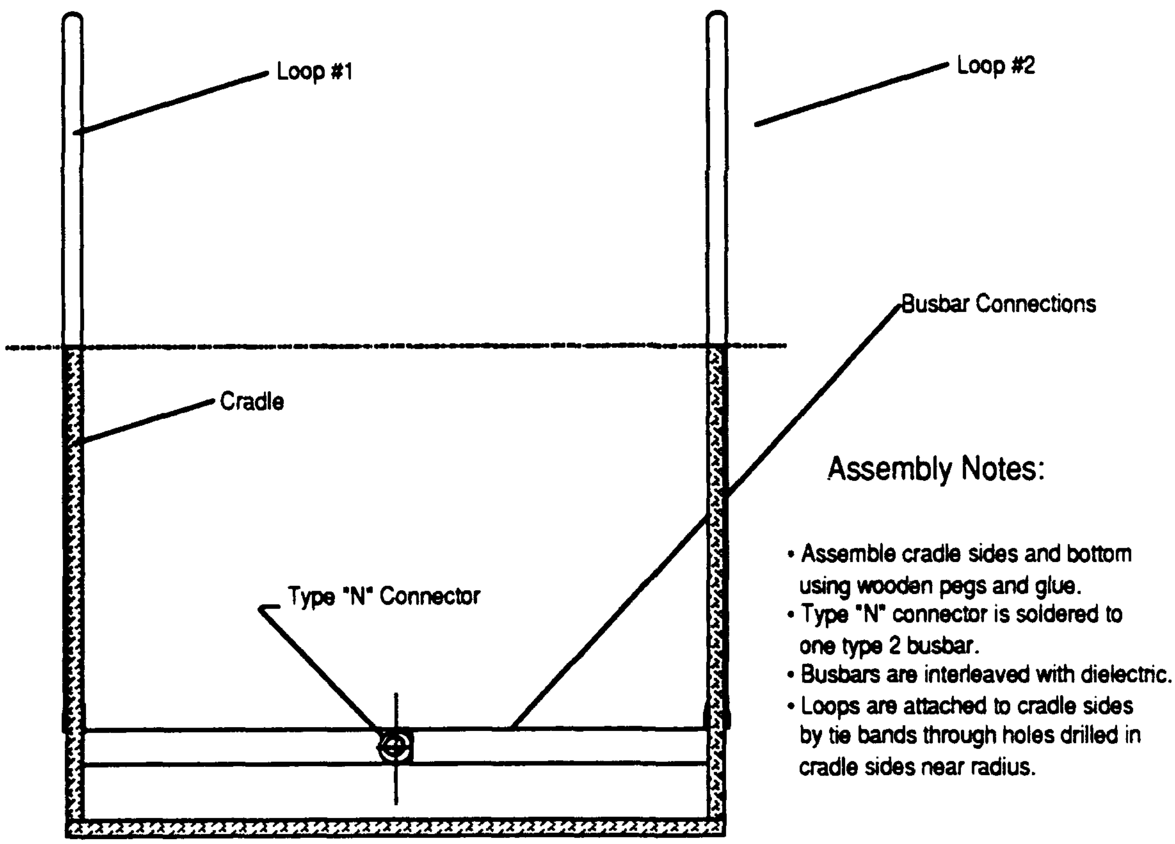



Figure 1. Helmholtz coil assembly – front.

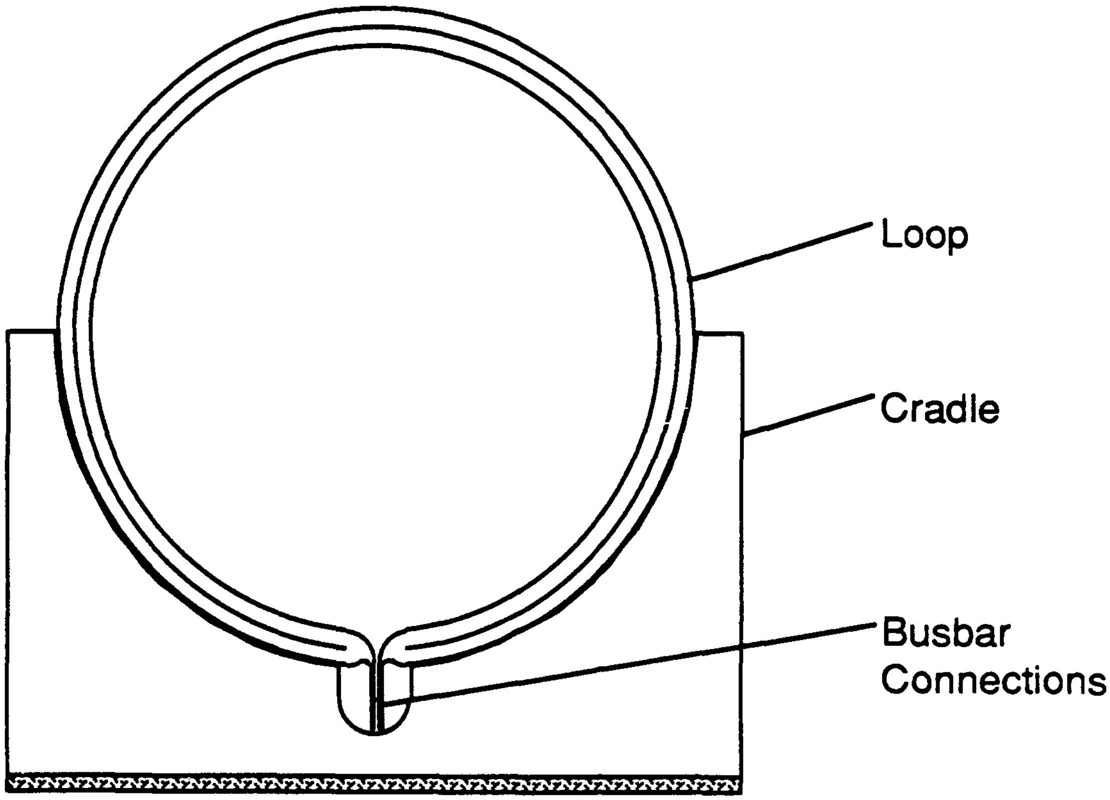



Figure 2. Helmholtz coil assembly – side.

The driver for the immediate application was defined as a capacitor discharge circuit as shown in Figure 3. Charging voltage is provided from a direct current power supply to the charging terminal (+DC). This terminal is connected via a normally closed relay contact to the charging resistor (R1) which subsequently charges the pulse capacitor (C1). The pulse current output is provided by the components C1, R4, Q1, and R5. The resistor R4 is the pulse current limiting resistor — an assembly of five strips of 0.001 inch thick steel shim stock, 0.2 inch wide by 18.5 inches long. These strips were assembled on an insulating board with separate wire leads so that series/parallel arrangements can be summed between the screw terminals shown. Switching of the current is provided by the silicon controlled rectifier (SCR) Q1. A solid state switch was used so that a pulse waveform could be achieved which was free of contact bounce, as is many times experienced with mechanical switches. The resistor R5 is a 10 milliohm noninductive current monitoring shunt for viewing and measurement of the pulse waveform via an oscilloscope. Triggering of the SCR is provided by the components S1, K1, R2, and R3. When the pulse is desired, the pushbutton S1 is depressed which causes pull–in of the relay K1. The normally open K1 contacts close and provide current to the R2,R3 stack. Resistor R2 limits the current drawn by the SCR's gate and R3 prevents overvoltage on the gate. This causes triggering of the SCR and discharge of C1's energy into the Helmholtz coil. Since the normally closed K1 contacts are now open, the SCR will cease conduction when the charge on the capacitor C1 is expended. The system is reset for another cycle by release of the switch S1 so that recharge of the capacitor can take place.

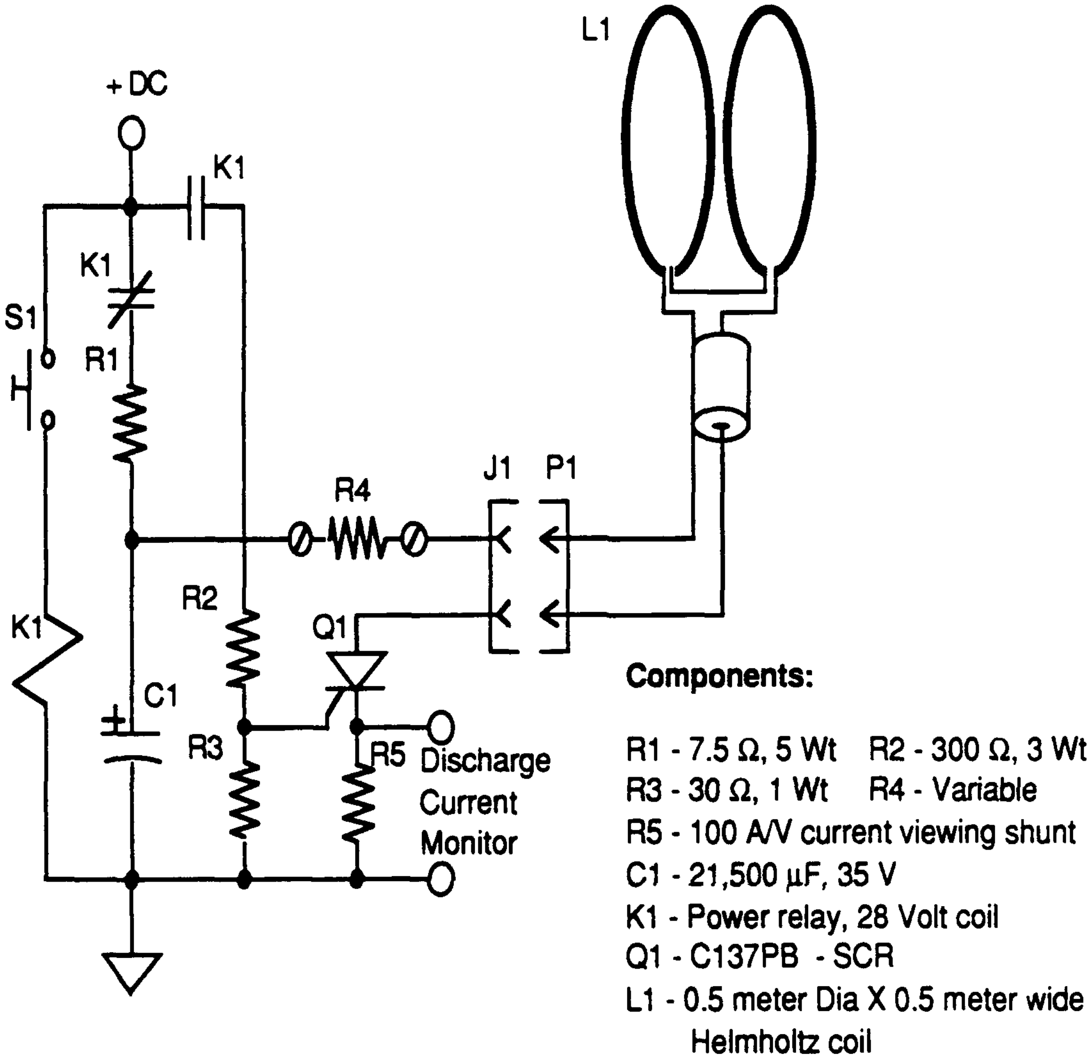



Figure 3. Schematic circuit of Helmholtz coil.

## III. CONSTRUCTION

The Helmholtz coil was built from parts whose design is shown in the shop drawings of the Appendix (Figures A1 through A4). The busbars were insulated with 0.125 inch thick polyethylene sheet which extended at least 0.5 inch beyond the busbar outline. This enables the coil to be driven with a short pulse of several thousand volts to create very strong pulsed magnetic fields, should that be required in future applications. In addition to the assembly shown in Figures 1 and 2, a wooden trestle approximately one foot wide by one foot tall and two feet long was built to hold test articles on the solenoidal axis.

## IV. CALIBRATION AND TESTING

The initial use of the Helmholtz coil was to provide a transient magnetic field which would cause a substantial anomaly as compared to the Earth's magnetic field. From references, it was found that the Earth's magnetic field at Washington, DC is:

$$B_{horz} = 0.184 \times 10^{-4} \text{ Teslas} = 0.184 \text{ Gauss}$$

$$B_{vert} = 0.541 \times 10^{-4} \text{ Teslas} = 0.541 \text{ Gauss}$$

$$\text{Dip angle} = 71.2^\circ .$$

The vector value (one Earth field) of the magnetic field would be

$$B_e = \sqrt{B_{horz}^2 + B_{vert}^2} = 0.571 \text{ Gauss.}$$

The current required to generate the above field at the point on–axis and centered between the two turns of the coil can be found from the relation

$$B = \mu_0 \frac{t\,r^2\,I}{2\,b^3} ,$$

where

$\mu_0 = 4\pi \times 10^{-7}$ Webers per Amp–meter

$B$ = magnetic flux density – Teslas

$I$ = current – Amps

$t$ = number of turns – 2 each

$r$ = radius of turn – 0.25 meter

$b$ = slope distance from coil circumference to the on–axis center point of the assembly – 0.3536 meter.

Solving for the current required for one Earth field yields:

$$I_e = \frac{2 B_e b^3}{\mu_0 t r^2}$$

$$= \frac{2\left(0.571 \times 10^{-4}\right)\left(0.3536\right)^3}{4\pi \times 10^7 \times 2\,(0.25)^2}$$

$$= 32.14 \text{ Amps.}$$

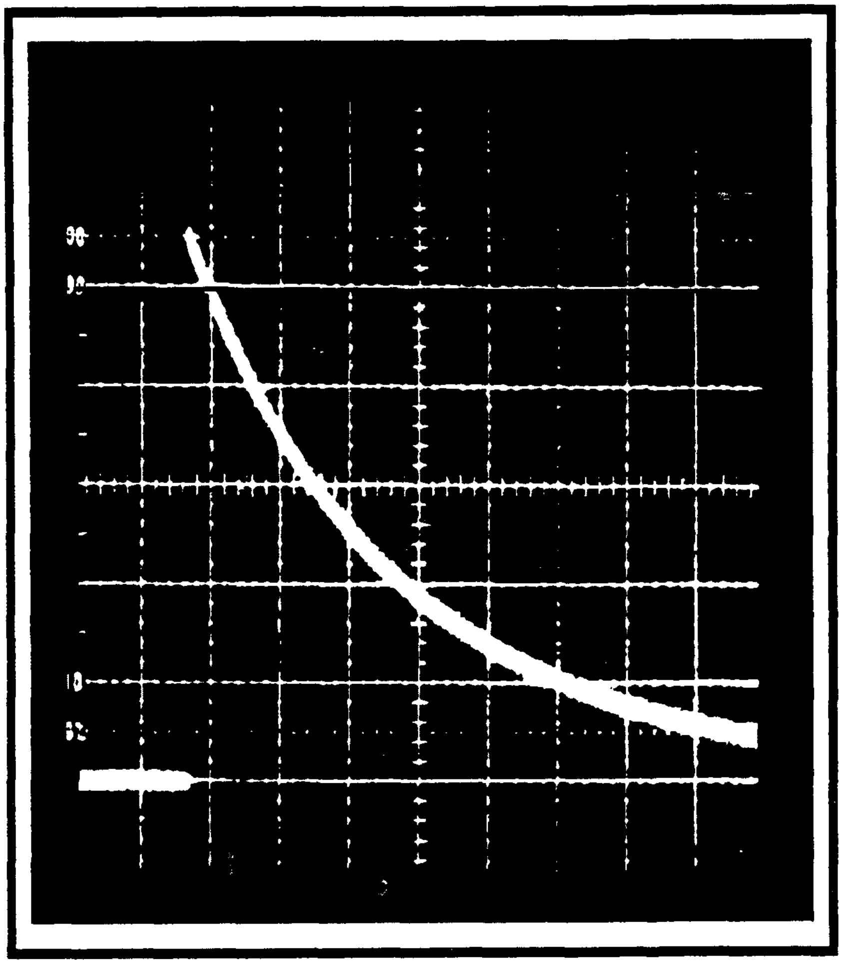
This current can readily be provided by simple pulse or continuous current circuitry. The magnetic versus current value of coil factor = $B_e \backslash I_e$ = 17.78 milligauss per amp.

In order to calibrate the Helmholtz coil, it was wired in series with a variable power resistor and an AC amp meter. This was connected to the output of an AC mains powered variable transformer. This output was monitored by an AC voltmeter. A Walker Scientific, Inc. ELF field monitor model number ELF–50D was located at the on–axis center point to display the magnetic flux density in milligauss. The voltage and magnetic flux density was read as the current was varied for 50 ohm and 25 ohm settings of the power resistor. The results of this test are shown in Table 1. Ten measurements were taken from 0.5 amps to 5.0 amps and the coil factor in milligauss per amp was calculated for each, as shown. The coil factors for the 0.5 amp and the 3.5 amp tests were excluded since they were inconsistent with the others, and the remaining eight values were averaged for a final coil factor. This average value is 16.04 milligauss per amp — as compared to the calculated 17.78 milligauss per amp — about 10% difference between analytical and experimental values. Considering that the available voltage, current, and magnetic flux instruments were only of ordinary accuracy, this value of difference is to be expected.

The Helmholtz coil was then driven by the impulse circuit shown in Figure 3. The oscilloscope display of current waveform (as represented by the current viewing resistor R5) was photographed and is shown in Figure 4. In order to obtain the peak value of the magnetic field, the peak vertical value of beam deflection is read (5.5 cm), and the oscilloscope vertical scaling (50 millivolt/cm) and the scale factor of the R5 current viewing resistor (100 amps per volt) are applied. As shown in Figure 4, this yields a peak magnetic flux density of 441.1 milligauss at a peak current of 27.5 amps. This value of magnetic flux density is close to that of the Earth field (571 milligauss) and within the operating bounds of the driver circuit so the simulation of a substantial anomaly of the Earth's magnetic field can readily be accomplished.

TABLE 1. Current Vs. Magnetic Field Density Calibration

| Current<br>Amps | Magnetic Field Density<br>Milligauss | AC Voltage<br>Volts | Load Resistance<br>Ohms | Coil Factor<br>Milligauss/Amp |
|---|---|---|---|---|
| 0.5 | 6 | 25.2 | 50 | 11.9048 |
| 1.0 | 15 | 50.4 | 50 | 14.8810 |
| 1.5 | 23 | 75.0 | 50 | 15.3333 |
| 2.0 | 32 | 100.5 | 50 | 15.9204 |
| 2.5 | 41 | 125.5 | 50 | 16.3347 |
| 3.0 | 48 | 75.0 | 25 | 16.0000 |
| 3.5 | 56 | 87.4 | 25 | 13.7300 |
| 4.0 | 66 | 100.3 | 25 | 16.4506 |
| 4.5 | 75 | 112.5 | 25 | 16.6667 |
| 5.0 | 84 | 125.6 | 25 | 16.7197 |



Vert Scale = 50 milliVolts / cm

Horz Scale = 10 milliseconds / cm

Current Shunt = 100 Amps / Volt

Series Resistance = 1 Ohm (approx.)

Figure 4. Pulse current waveform of Helmholtz coil.

## V. CONCLUSIONS

Based on the calibration run described here, the Helmholtz coil is seen to provide a useable magnetic field for the testing of smaller items. To have a consistent field exposure, the test article should not be more than one foot in any dimension — this limit encompassing all items to presently be exposed. The evaluation of the results of such tests must be conducted with the knowledge that the instruments available for this calibration of the Helmholtz coil were only of "lab–bench" accuracy. Moreover, the wave shape of the pulse driving the generation of the magnetic field may not be representative of the magnetic anomaly that the test article actually encounters in service. However, the current requirement is for an expedient comparative test between two different items as opposed to a qualitative measurement of effect level. A more precise calibration and an impulse driver circuit designed to exactly simulate the required drive current waveform would substantially increase the ability to perform tests on an absolute basis. As stands, this Helmholtz coil and its driver circuit is quite useful for a number of testing purposes.

# APPENDIX

APPENDIX

The drawings in this appendix, taken with Figures 1 and 2 as assembly drawings, comprise the shop drawings used to construct the Helmholtz coil. The 0.125 inch thick polyethylene sheet which was used to insulate the busbars is not shown since it was obtained after construction began. Likewise, the details of connection of the type "N" coaxial connector are not shown since that design was created as the work progressed. Insulation in the busbar area is the primary limit to the maximum magnetic field that could be generated. From engineering experience with similarly insulated systems, the busbar insulation should hold off about 10 KV on a short pulse basis.

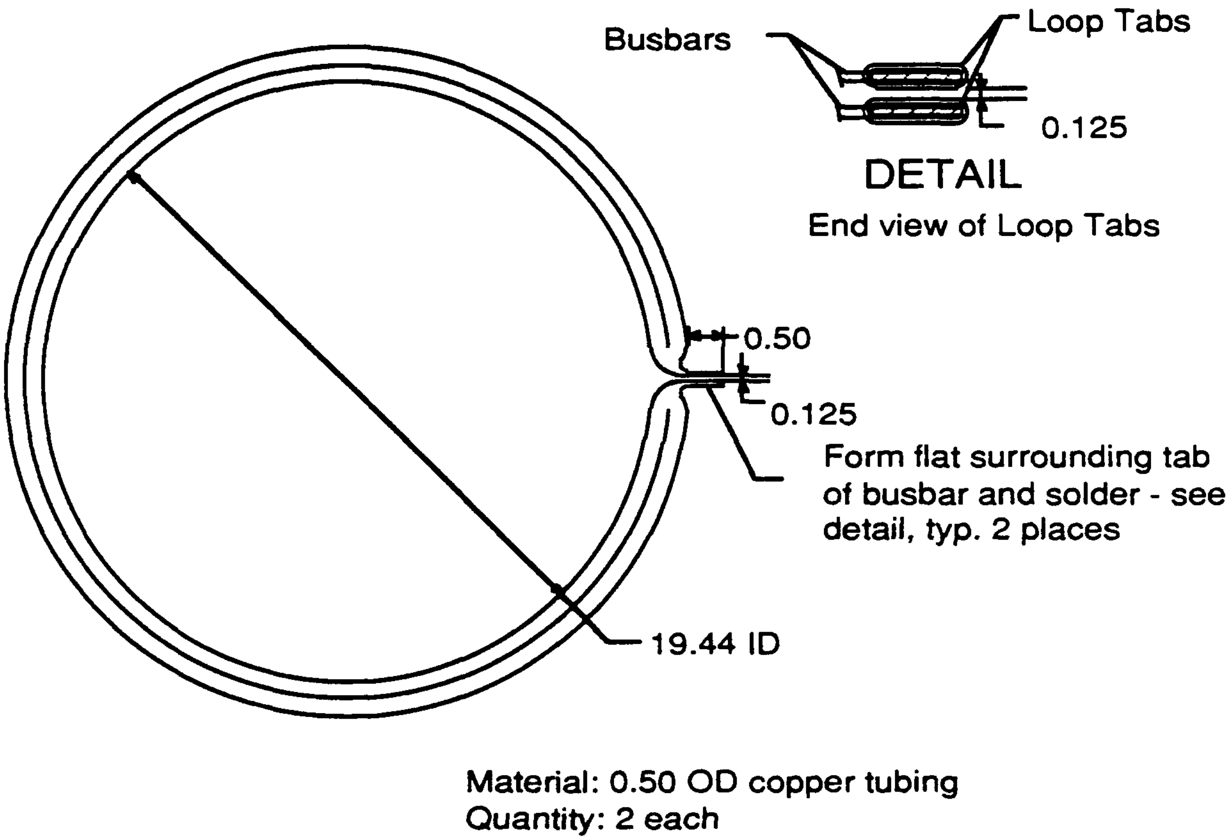
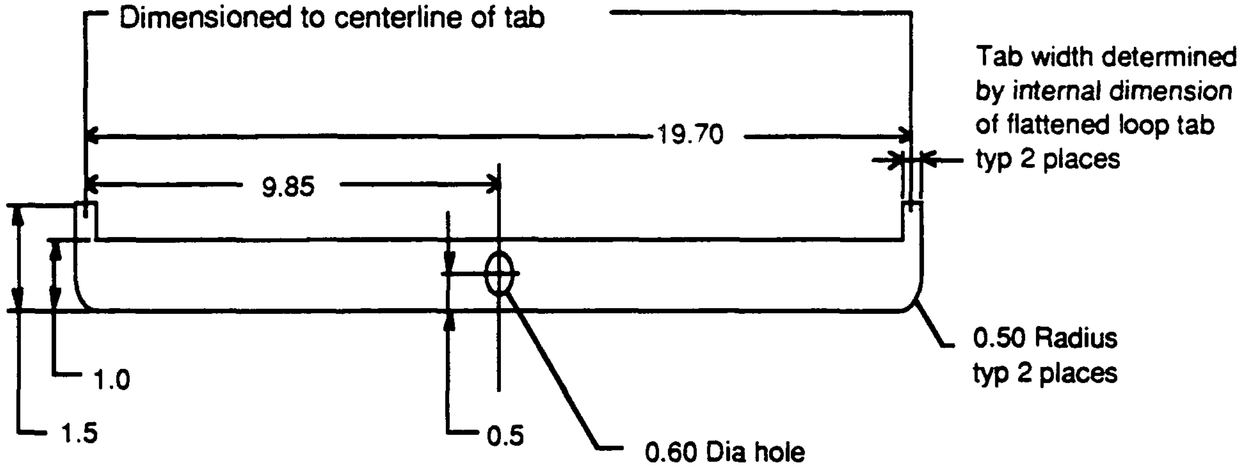
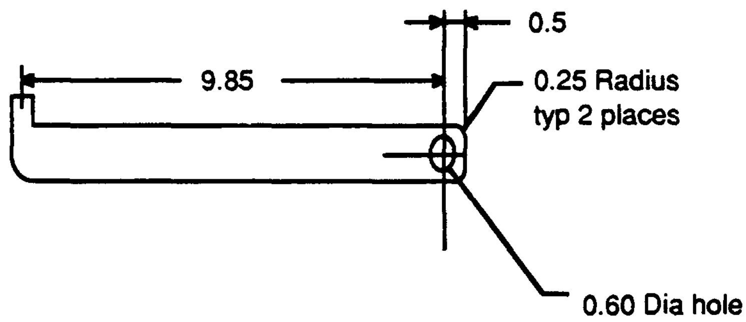



Figure A1. Helmholtz coil – loop.



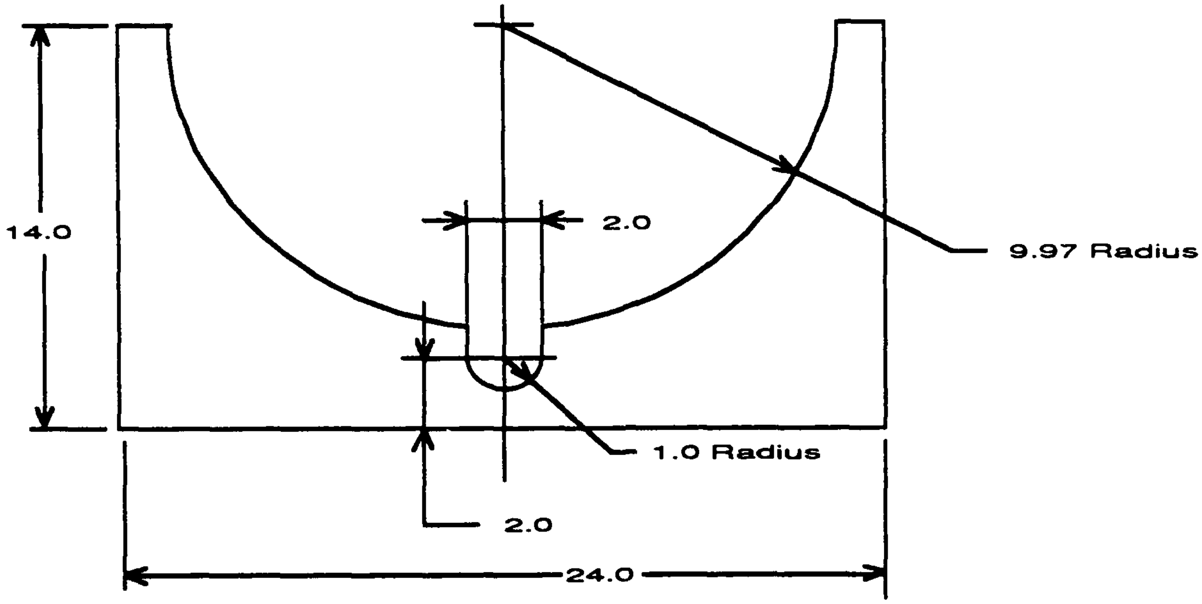

Busbar Type 1




Busbar Type 2

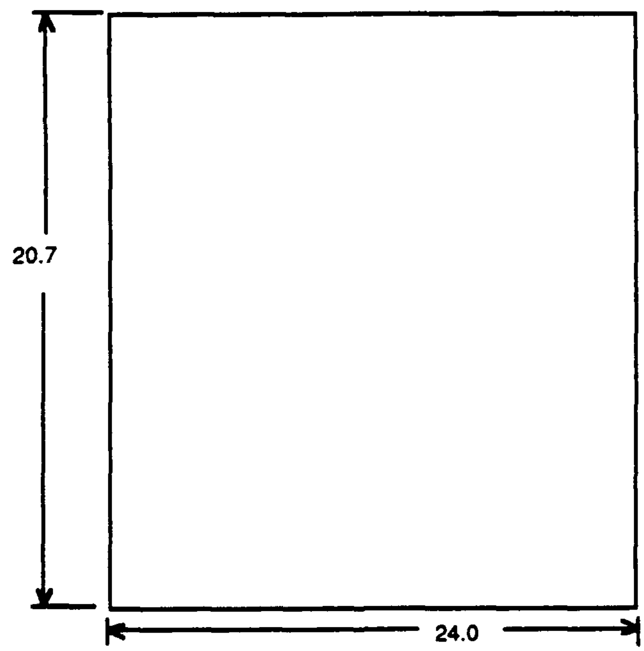
Material: Copper sheet 0.064 thick
Quantity:
Type 1 - 1 each
Type 2 - 2 each

Figure A2. Helmholtz coil – busbars.




Material: Plywood - 0.5 thick
Quantity: 2 each

Figure A3. Helmholtz coil – cradle side.




Material: Plywood - 0.5 thick
Quantity: 1 each

Figure A4. Helmholtz coil – cradle bottom.

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